

## THE SYSTEM AND IMPLEMENTATION ASPECTS OF THE MARS ADVANCED RADAR FOR SUBSURFACE AND IONOSPHERIC SOUNDING (MARSIS).

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**ABSTRACT:** MARSIS is a subsurface and ionospheric radar sounder with operating frequency in the range of 1.3-5.5 MHz and 0.1 to 5.5 MHz respectively. It will be flown on the ESA Mars Express spacecraft. MARSIS is designed to sense the planets subsurface to a depth of up to 5 km. MARSIS' main objective is to search for water if it exists in liquid form under the surface. It will also attempt to map and characterize the subsurface geological structure of Mars, which is hidden under a layer of surface dust. In this paper, the sounder instrument and its design constraints and parameters described. Limitations imposed by both the ionosphere that surrounds Mars and the surface and subsurface characteristics drive the instrument design along with constraints imposed by the spacecraft. Limitations on the spacecraft data system has resulted in a design which incorporates an on board data processor which reduces the data transmission requirements between the spacecraft and the ground.

**Introduction:** MARSIS is a radar sounder operating in the HF frequency range to sound the subsurface of Mars and its ionosphere. MARSIS is one of the seven instruments aboard the ESA Mars Express spacecraft [1] scheduled for launch from Baikonour, Russia in June 2003 and will arrive in orbit around Mars in early 2004 for a two-year mission. This sounder is the result of an international collaboration between NASA, the Italian Space Agency (ASI), and European Space Agency (ESA). The main objective of MARSIS is to search for water if it exists in liquid form under the surface to a depth of 5 Km. It will also attempt to map and characterize the subsurface geological structure of Mars, which is hidden under a layer of surface dust. In addition to its subsurface exploration goals, MARSIS will study the ionosphere of Mars providing the most extensive amount of data on Martian ionosphere to date. The design requirements for this sounder is to detect a water/ice boundary at a depth of up to 5 kilometers under the crust of Mars. The depth resolution requirement is 100 meters in the material with an spot size of 10 kilometers or less. These requirements have led to an instrument with a total mass of 17.2 Kilograms, uses 65 watts of spacecraft power, has a data rate of between 16 Kbps and 80 Kbps and uses a 40 meter tip to tip dipole as its principal antenna. This design of MARSIS is a tradeoff between the expected penetration into the Martian subsurface that is proportional to the wavelength of the system and the desire to operate at a short wavelength in order to minimize the effects of the ionosphere.

**System aspects:** The design of the sounder system is driven by 1) the attenuation of the crust of the martian surface, 2) the spacecraft accommodations to a long dipole antenna and 3) the attenuation and dispersion effects of the ionosphere. In order to penetrate the martian surface to a depth of 5 Km, it is desirable to operate the sounder at a frequency which is as low as possible consistent with the resolution requirements. However, the Martian ionosphere prevents operation at frequencies lower than 0.8 MHz at night time and 2.5 MHz during daytime. The attenuation of the ionosphere and frequency dispersion increases rapidly as the operating frequency approaches the plasma frequency. The plasma frequency is expected to vary from 0.5 MHz at high solar zenith angles to 3 MHz when the solar zenith angle is less than 60 Degrees. MARSIS uses 4 frequency bands for sounding the subsurface that have center frequencies of 1.8 (Band 1), 3.0 (band 2), 4.0 (Band 3) and 5.0 (Band 4) MHz. The resolution requirements impose operation at each of these bands with a bandwidth of 1 MHz. A fifth band from 0.1 MHz to 1.3 MHz is used for ionospheric sounding only.

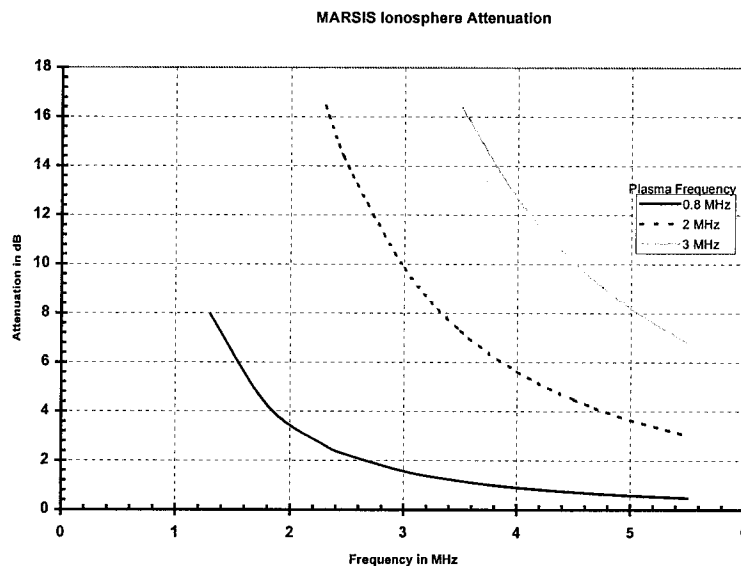
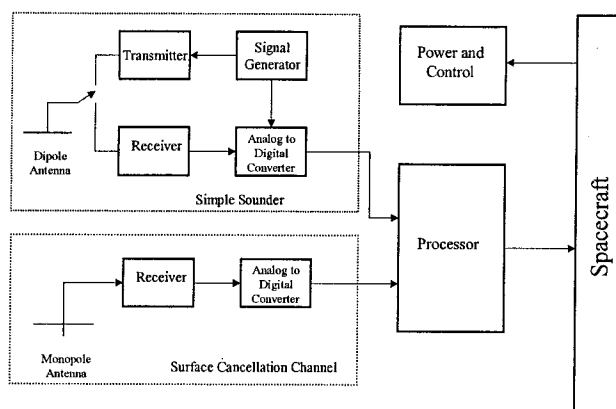


Figure 1 Expected MARSIS Ionosphere Attenuation

MARSIS, when operating in the active ionospheric sounding mode covers the 0.1 MHz to 5.5 MHz frequency range. For the subsurface sounding mode of operation, transmission at two simultaneous bands is possible with a slight time displacement used as the method for isolating the returns. Radio signal transmission is through the 40 meter dipole antenna and as shown in the MARSIS block diagram of Figure 1, echo reception is through both the dipole and monopole antennas. The antenna length is limited by the design of the Mars Express spacecraft. The dipole antenna length is naturally resonant at a frequency of 3.75 MHz. At frequencies below this value, a matching network is used to couple energy between the transmitter electronics and the antenna. The desire to uniformly couple energy from the transmitter electronics to the antenna over a wide band range of frequencies results in a network with reduced efficiencies. For the subsurface

sounding, two networks are utilized. The first operates for frequencies substantially below the antenna resonant frequency while the second for frequencies slightly below to the maximum frequency of operation. The transmitted signal is a nominal 250 microsecond linear frequency swept pulse.



**Figure 2 MARSIS Block Diagram**

The instrument mass is 17.2 Kilograms and the current best estimate of the mass distribution among the sounder elements is as follows.

Element	Mass
Transmitter	4.1
Receiver	1.8
Antennas	6
Digital Electronics	3.9
Cabling	0.9
Antenna Interfaces	0.5
<b>Total</b>	<b>17.2</b>

**Table 1 MARSIS Mass Budget**

The total DC power during sounding operations is 65 watts.

**Instrument Operation:** The Mars Express spacecraft will be in an elliptical orbit around Mars with a periapsis of 250 Km and an apoapsis of 10,124 km. The sounder will begin to acquire ionospheric data when the orbiter altitude descends to 1200 km above the Martian surface and will switch to acquire subsurface sounding data when the altitude reaches 800 km. The duration of each of these subsurface sounding passes is expected to be 26 minutes. In the subsurface sounding mode, the transmitter generates a nominal 250  $\mu$ sec linear FM transmitted signal at one of the frequency bands. The selection of the operating frequency bands will be made based on the expected local solar zenith angle. For significant penetration of the surface, it is desired to operate at a RF frequency that is as low as possible. The ionosphere of Mars limits how low a fre-

quency can be used for subsurface sounding. The ionosphere of Mars prevents operation at frequencies below 2.5 MHz when the solar zenith angle is less than 80 degrees and at frequencies below 0.8 MHz during nighttime [3,4,5]. Upon reception of the echo, these signals are converted to digital form using an analog to digital converter, fourier transformed to the frequency domain and stored on board the local Digital Signal Processor memory. If the mode calls for a second frequency of operation, the process is repeated with the second frequency band. The sounding data are acquired in data "frames" which correspond to the size of the expected fresnel zone size on the surface and represent data blocks of between 100 and 300 transmitted pulses. This frequency domain data are stored in the on-board a computer which performs fourier transformation in the doppler direction at the completion of acquiring data for the data frame. Due to the dispersive effects of the ionosphere, a special processing is needed to compensate for the ionospheric phase distortions. The science data is corrected on the ground where it is possible to achieve the highest quality correction. However, radar functions such as acquisition and tracking of the signal require on-board ionospheric phase corrections. For this purpose, two methods based on "contrast enhancement" and "front-surface-reflection" available on-board. This compensation is required in order to correct for the phase errors expected to be introduced by the ionosphere as well as errors introduced by the antenna matching network. The instrument incorporates a total of five subsurface sounding modes and depending on the particular mode selected, the desired portion of the doppler spectra will be sent back to earth. These modes select the number of frequencies that can be selected, the selection of the clutter cancellation channel, the number of doppler filters which will be sent back to the ground and the use of a pre-summer. The following table shows the characteristics of each of these modes.

Operating Modes						
Mode	Frequencies	Clutter Cancel	Pre-Sum	Doppler Filters	Data Rate Kb/Sec	Comments
SS1	2	Y	N	1	26.1	Complex data on ground
SS2	2	N	N	1	13	Amplitude only on ground
SS3	2	N	N	3	39	Multilook on ground
SS4	1	Y	N	5	65.2	Dual Channel coherent cancellation on ground
SS5	1	Y	Y	3	39	Presum 30 microsecond pulses. Avoid sidelobe problems
AIS	160	N/A	N/A	N/A	33	Active Ionospheric Mode
Raw Data	1/2		N	N/A	25.4	Raw Data Two Channel. Buffered

Table 2 MARSIS Operational Modes

An examination of the surface slope distribution from the MOLA laser altimeter indicates that the surface of Mars has a RMS slope of less than 2 degrees with an RMS height distribution of 3 meters for 90 percent of the surface. For a surface with this low roughness, the subsurface returns are expected to be stronger than the surface clutter after the planned Doppler filtering. For the remaining 10 percent of the surface of Mars, the surface roughness has a greater slope distribution and a higher RMS height. For these rough areas, the return from the surface clutter is expected to dominate over the subsurface returns. In order to separate the surface returns from the subsurface returns, the MARSIS design incorporates a second receive only channel with an antenna that exhibits a null in the nadir direction. The purpose of this second, or surface clutter

cancellation channel is to receive mostly off-nadir surface returns. These surface returns can be subtracted from the returns of the main channel reducing the effects of the surface clutter level. This clutter removal takes place on the ground as both returns from the dipole and clutter cancellation channel are separately returned. The antenna for the surface cancellation channel consists of a 7-meter monopole. The receive channel electronics after the antenna is identical to the subsurface sounding channel.

Each of the two receiver channels first performs RF amplification prior to down conversion to an intermediate frequency of 0.7 MHz. The returns are filtered in their native frequency range and subsequently at the intermediate frequency. The receivers have a range of gain between 33 and 73 dB prior to conversion to a digital format by an 8 bit A/D converter. The data are first buffered prior to transmission to the data processor. The digital processing section can take a portion of the digital data in an unprocessed form for telemetry to the ground or it can process the return echos in a dual DSP processor.

The control of the MARSIS instrument is via an Operation Sequence Table (OST) which contains all the necessary control parameters for a data pass. It is possible to command the instrument in approximately 1 second intervals. This OST is calculated on the ground and telemetered to the Mars Express Spacecraft prior to each orbital pass.

**Data Processing:** The subsurface sounder operates at a nominal pulse repetition rate of 127 Hz and acquires sounding data in frames of approximately 1 second in duration. The sounding data is quantized at a rate of 2.8 Megasamples per second at an 8 bit per sample level. Each return is converted to digital form for an echo duration of 350 microseconds. The resulting data rate per channel is 1 Mbps which is significantly over the 30 to 80 kbps rate allowed by the spacecraft data system. In order to reduce this rate, MARSIS employs an on board data processor consisting of 2 DSP processors. The Digital Electronics Subsystem (DES) first converts the digitized echos to the frequency domain and stores the contents in memory. After the contents of a full frame are received, the returns are converted to doppler and the contents of the desired doppler band returned to earth. The resulting data rate is 16 Kbps per channel. Depending on the mode selected, the data may be combined from separate doppler filters to form multilook data or the returns from a single doppler filter returned to the ground. The data returned are in the frequency domain in order to reduce computation demands on the processor and data volume per frame of data. These data contain the dispersion effects of the ionosphere and this phase distortion is detected from the front surface reflection. The effects of the ionospheric distortion are then removed from the sounder data on the ground to achieve the best performance.

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